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Abstract

Major efforts over the past six months included: (i) post-delivery work on the cloud optical depth (MOD_PR06OD) algorithm; (ii) preliminary analysis of MAS and CAR data from the FIRE III Arctic Cloud Experiment, conducted in Fairbanks and Barrow, Alaska, during May and June 1998; and (iii) continued work on previous experimental data sets.

I. Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR), our primary objective is to extend and expand algorithms for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

II. Work Accomplished

a. MODIS-related Algorithm Study

Ice Cloud Retrievals

Current ice cloud reflectance libraries being used for retrievals are based on ice particle scattering calculation performed by Professor Kuo-Nan Liou's research group at UCLA. These calculations are based on a predetermined combination of ice particle shape and sizes. A theoretical sensitivity study of ice cloud reflectances as a function of particle shape/size has been proposed for understanding the particle size information content contained in retrievals. This fundamental work will lead to an improved ice cloud retrieval algorithm that will be developed and tested using MODIS Airborne Simulator (MAS) data flown aboard the NASA ER-2 research aircraft. The sensitivity study will also improve our understanding and implementation of a visible/near-IR thermodynamic phase algorithm (post-launch) which is also under development.

In support of this effort, Bryan Baum of Langley Research Center developed a driver program for the discrete ordinates radiative transfer code DISORT (Tsay et al., 1990) specifically for use with MODIS and MAS bands. This driver includes not only effects of Rayleigh scattering above clouds, but also correlated-*k* distributions to account for atmospheric absorption. This code was tested extensively by Bryan Baum and Peter Soulen.

Bryan Baum has taken the lead in developing a more spectrally comprehensive thermodynamic phase algorithm (post-launch). Dr. Baum is developing an algorithm that begins with the 8.5-11-12 µm band algorithm of Strabala et al. (1994), and then incorporates additional information by using differences in reflectances between near-infrared and visible bands. Originally, daytime thermodynamic phase discrimination was expected to use ratios of reflectances. However, Bryan Baum has determined that using ratios for purposes of phase discrimination works well only over dark surfaces such as ocean or snow (where surface reflectance for the 1.6 and 2.1 micron bands is dark). Ratios of reflectances over bright surfaces incorporate too much variability to be useful in phase discrimination. Bryan Baum is now developing a new algorithm that uses differences in reflectances over different land types using the new driver.

After Professor Liou's research group delivered ice cloud phase functions with the final MODIS spectral response functions (SRFs), Peter Soulen recalculated the ice cloud libraries using routines provided by Prof. Teruyuki Nakajima (Nakajima and Tanaka, 1988; Nakajima and King, 1992). All but one of the final ice libraries has been calculated. To avoid having to store reflectances and transmissions of clouds for many optical thicknesses, the MOD06 level-2 cloud retrieval code uses asymptotic theory to calculate reflectances and transmissions of clouds as needed, using specially calculated parameters and functions, which dramatically saves memory. In contrast to the phase functions for water clouds generated by Steve Platnick, the phase functions provided by Prof. Liou's group are truncated, i.e., they do not include the large forward peak caused by diffraction. Unfortunately, Prof. Nakajima's routines for generating the libraries are not designed for truncated phase functions. However, Nakajima and King (1992) suggest that it should be straightforward to modify the existing routines, and Prof. Nakajima himself is now working through the modifications. Another option is to simply "un-truncate" the phase function in some suitable way, rendering it appropriate for the existing code. We expect we will complete modifications to the current library generation code shortly. In the meantime, work is underway to double-check the retrieval libraries by generating them using the new driver for DISORT.

Peter Soulen, using the new driver, performed preliminary calculations that demonstrated that retrievals of optical thickness for ice clouds might depend significantly on crystal size and/or habit. Unfortunately, the phase functions provided to us by Prof. Liou's group are mixtures of various sizes and habits, so that it is not possible to determine how much crystal size and habit affect cloud reflectance, and how our retrievals could be biased. Prof. Liou's group has been asked to perform further computations of phase functions at discrete sizes and pure habits for wavelengths used by MODIS and MAS so that we can generate our own phase functions using the spectral response functions for MODIS or any MAS experiment desired, with any mixture of sizes and habits we choose. Once this work is completed, Peter Soulen will use the driver to perform a sensitivity study of how well optical thickness and effective radius can be retrieved with crystals of different sizes and habits.

In addition, recent work by Andrew Heymsfield at NCAR suggests that ice clouds should not be treated as vertically homogeneous, but instead as vertically inhomogeneous with three layers: a top layer of relatively small, round crystals; a middle layer of extended habits, such as bullet rosettes and columns; and a bottom layer of aggregates (columns randomly mashed together). Bryan Baum and Peter Soulen are in the process of adapting the driver for a sensitivity study of optical thickness and effective radius retrieval for vertically inhomogeneous ice clouds, building upon the work of Platnick (1998), who examined retrieval of effective radius for vertically inhomogeneous water clouds.

b. MODIS code delivery

MOD06 level-2 cloud retrieval code

Mark Gray has taken over management of the MODIS level-2 cloud retrieval code (MOD06OD). Several problems and standards violations were revealed by SDST and a new baseline code package was submitted for testing in August. In September, operator actions were added to output error messages. In October during testing with MODIS Airborne Simulator data from FIRE/ACE a major output data quality issue was identified and linked to the cloud phase change handling code. This problem has now been resolved. Gray is planning a major re-design of the MOD06OD package.

MOD08 level-3 atmosphere code

All error messages in the MOD08 (MODIS Joint Atmospheres Product) software were modified to conform to a new format requiring that error messages include a recommended operator action. The software for MOD08 includes three HDF structure file creation modules and three science modules, one each for the Daily-Tile, Daily-Global, and Monthly-Global products. The HDF structure file creation modules are identified as MOD_PR08TC, MOD_PR08DC, MOD_PR08MC. The science modules are identified as MOD_PR08T, MOD_PR08D, and MOD_PR08M. All software was successfully run and then redelivered to SDST between November 1998 and January 1999. The code is currently being tested by SDST.

A preliminary MOD08 web site (http://ltpwww.gsfc.nasa.gov/mod08) was developed. The site is still under construction.

c. MODIS-related Instrumental Research

<u>*CAR BRDF processing*</u>

All CAR data from LEADEX and ARMCAS deployments have been analyzed by Tom Arnold and specific cases of sea-ice and tundra BRDFs have been selected for publication. Arnold has written a first draft of a paper. The paper presents multi-wavelength BRDF observations of sea-ice and tundra in early spring (sub-freezing) conditions and late spring (melting) conditions. Figures 1 and 2 (for two CAR bands) show sample polar BRDF plots for early and late spring sea ice and tundra. Spectral albedo has also been computed for each BRDF case and compared to the nadir reflectance.

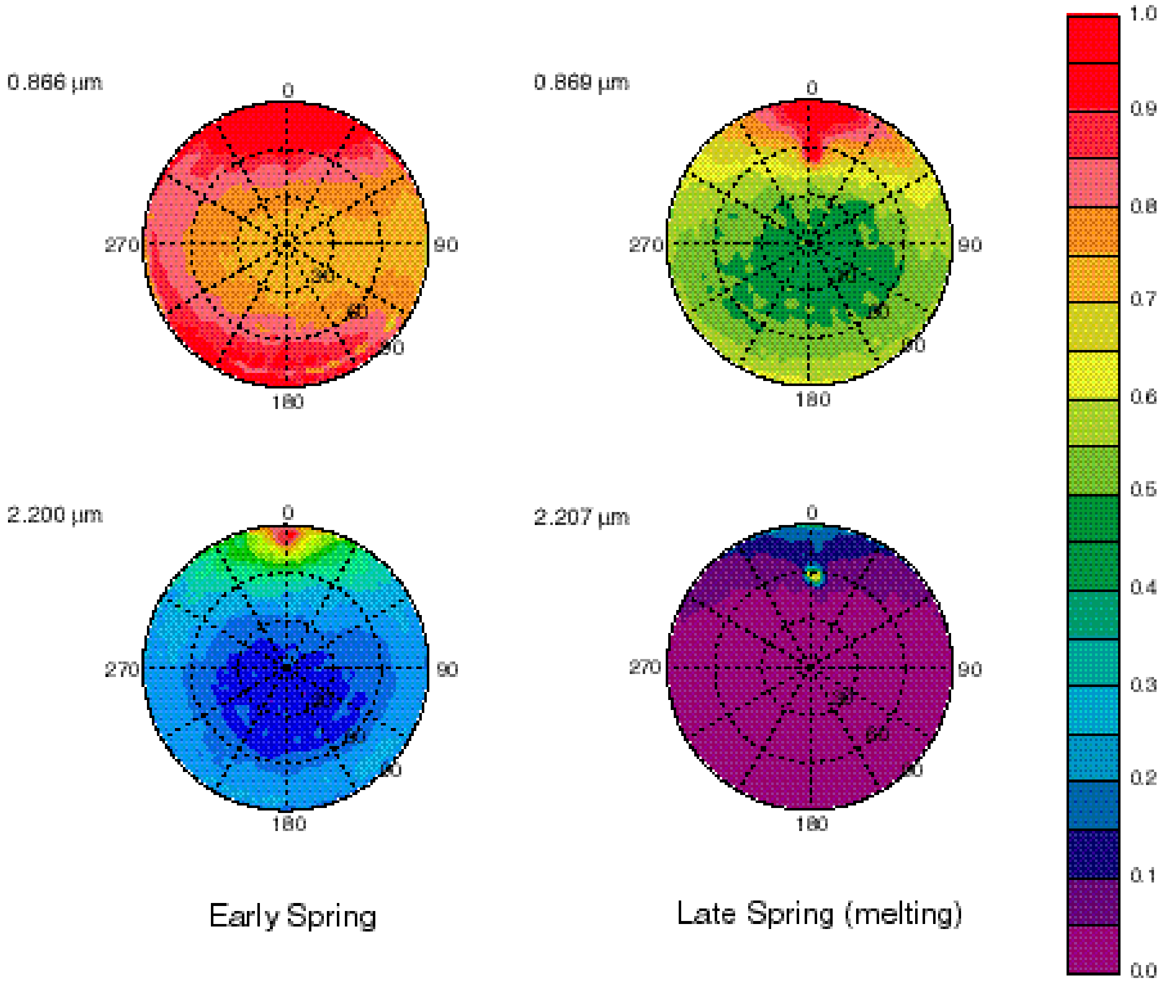

Figure 1. Sea ice reflectance in early and late spring.

Raw SCAR-A (1993) and Kuwait (1991) CAR data have been reprocessed and BRDF cases selected and processed (producing BRDF polar plots, principal plane plots, and summary tables of albedo and nadir reflectance). For several SCAR-A cases it was necessary first to perform a roll correction of the data.

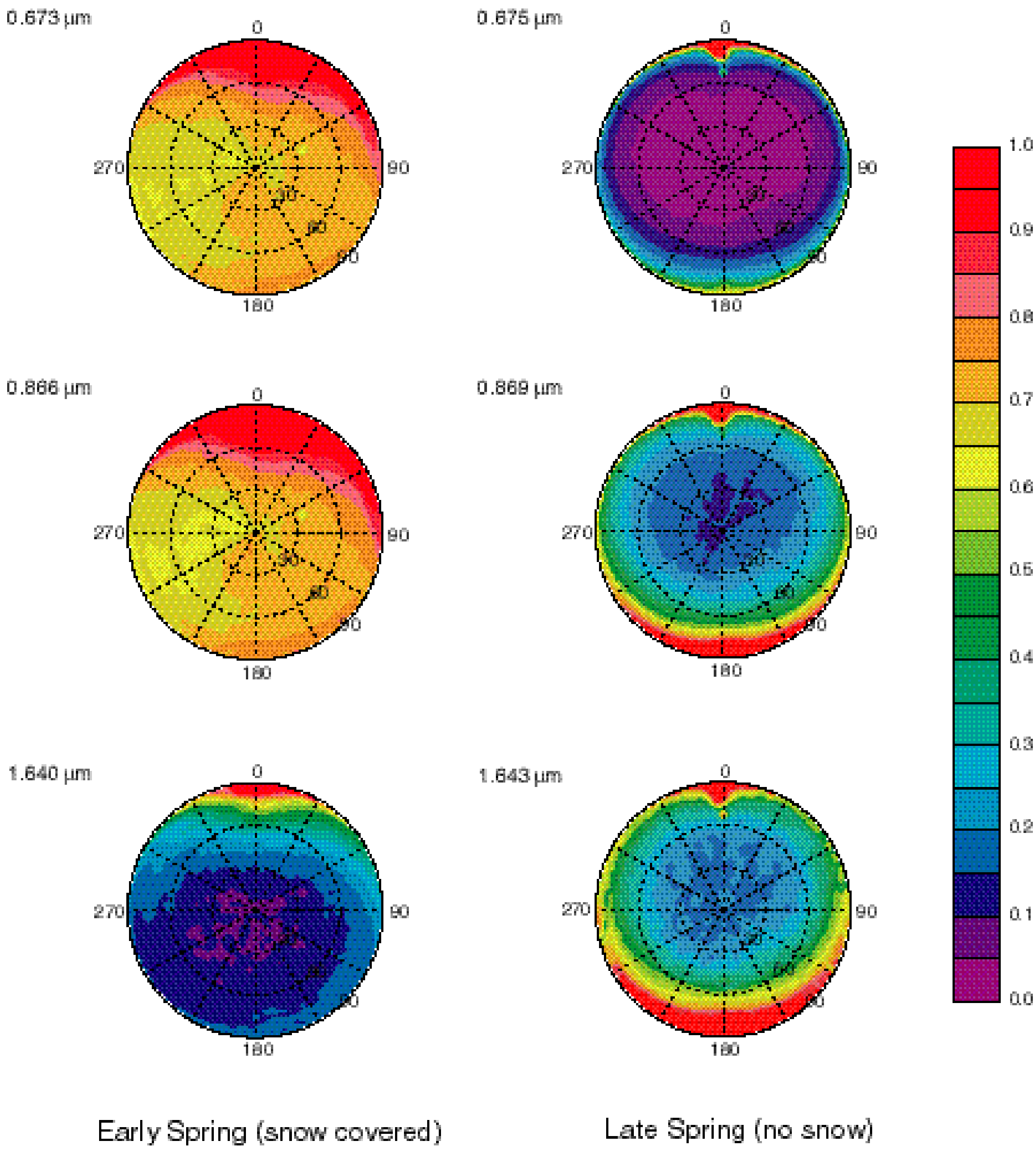

Figure 2. Tundra reflectance in early and late spring.

d. MODIS-related Services

Meetings

1. Si-Chee Tsay and Michael King attended the *International Geoscience and Remote Sensing Symposium*, Seattle, WA, 6-10 July 1998, and Si-Chee Tsay chaired a session entitled "Remote sensing from the Earth Observing System AM platform."

2. Michael King and Si-Chee Tsay attended the SAFARI 2000 Workshop in

Blydepoort, South Africa, 12-17 July 1998.

3. *MODIS Airborne Simulator Meeting*, Madison, WI, 4-5 August 1998. Attended by T. Arnold, M. Gray, P. Hubanks, M. D. King, J. Li, S. Platnick, P. Soulen, and S. C. Tsay.

4. Si-Chee Tsay attended the *Joint International Symposium on Global Atmospheric Chemistry* in Seattle, WA, 19-25 August 1998.

5. *MODIS Atmosphere Discipline Group Meeting*, St. Michaels, MD, 4-6 November 1998. Attended by T. Arnold, P. Hubanks, M. D. King, J. Li, S. Platnick, P. Soulen, and S. C. Tsay.

6. Peter Soulen attended a workshop at the University of Wisconsin, Madison, on 7-8 December 1998 to discuss the most recent experimental microphysical data for ice clouds, and to determine a strategy for determining the sensitivity of retrieved optical thickness and effective radius to assumed crystal size, habit, and vertical inhomogeneity.

7. *MODIS Science Team Meeting*, College Park, MD, 15-16 December 1998. Attended by M. Gray, P. Hubanks, M. D. King, S. Platnick, P. Soulen, and S. C. Tsay.

8. Michael King regularly attended weekly MODIS Technical Team meetings.

9. Michael King attended *Science Executive Committee* meetings in Chicago on 1 July, 2 September, and 17 December.

Presentations

1. King, M. D., W. P. Menzel, Y. J. Kaufman, D. Tanré and B. C. Gao, "Remote sensing of cloud, aerosol, and water vapor properties from the Moderate Resolution Imaging Spectroradiometer (MODIS)," presented at the *International Geoscience and Remote Sensing Symposium*, Seattle, WA, 8 July 1998 (invited).

2. Tsay, S. C., "Clouds, aerosols and their interactions: A climatic perspective," presented at the *SAFARI 2000 Workshop*, Blydepoort, South Africa, 12-17 July 1998.

3. King, M. D., "Earth Observing System—Science objectives and challenges," presented at the *SAFARI 2000 Workshop*, Blydepoort, South Africa, 12-17 July 1998.

4. Tsay, S. C., "Atmospheric effects: Signal or noise?" presented at the *Resource-21 Workshop*, Seattle, WA, 19-20 August 1998.

5. King, M. D., "Earth Observing System science, validation, and SAFARI

2000," presented to NASA, NSF, and START, NASA Headquarters, Washington, DC, 8 September 1998.

6. King, M. D., "Earth Observing System: Science objectives and challenges" presented at the *SPIE Symposium on Remote Sensing of the Atmosphere, Environment, and Space*, Beijing, China, 13-17 September 1998 (invited).

7. Tsay, S. C., "Southern Africa Fire-Atmosphere Research Initiative (SAFARI): MODAtmos' perspective," presented at the CERES Science Team meeting, Stony Brook, NY, 15-18 September 1998.

8. Tsay, S. C., "Clear-sky correction of Landsat data," presented at *EurOpto SPIE Conference*, Barcelona, Spain, 20-23 September 1998.

9. King, M. D., "Clouds, radiation, and climate from the Earth Observing System" presented at the *13th National Congress of the Australian Institute of Physics*, Fremantle, Australia, 2 October 1998 (invited).

10. King, M. D., "EOS algorithms and science," Independent Annual Review of EOS, Goddard Space Flight Center, 6 October 1998.

11. Tsay, S. C., "Application of path radiance for retrieving aerosol optical thickness over land," presented at the *MODIS Atmosphere Discipline Group Meeting*, St. Michaels, MD, 4-6 November 1998.

12. Platnick, S., "Cloud retrievals in the Arctic: Preliminary results from FIRE/ACE," presented at the *MODIS Atmosphere Discipline Group Meeting*, St. Michaels, MD, 4-6 November 1998.

13. Platnick, S., "The effect of vertical inhomogeneities on cloud droplet size retrievals, and information regarding the droplet size profile," presented at the *MODIS Atmosphere Discipline Group Meeting*, St. Michaels, MD, 4-6 November 1998.

14. Tsay, S. C., "ACE-Asia and AM-1 & PM-1/EOS: A 2000+ field campaign on Asian dust and pollution aerosol," presented at the *ACE-Asia Workshop*, Cheju, Korea, 10-13 November 1998.

15. Platnick, S., "Cloud retrievals in the Arctic: A few preliminary results for liquid water clouds from FIRE/ACE," presented at the *MODIS Science Team Meeting*, College Park, MD, 15-16 December 1998.

Seminars

1. King, M. D., "Earth Observing System: Science objectives and challenges," at the Dept. of Oceanography, University of Cape Town, Rondebosch, South Africa, 21 July 1998.

2. King, M. D., "Earth Observing System: Science objectives and challenges," at the Dept. of Earth Science, University of the Western Cape, Bellville, South Africa, 21 July 1998.

3. King, M. D., "Earth Observing System: Science objectives and challenges," at the Dept. of Electrical & Electronic Engineering, University of Stellenbosch, Stellenbosch, South Africa, 22 July 1998.

4. King, M. D., "Earth Observing System: Science objectives and validation," at the CSIRO Marine Laboratories, Hobart, Australia, 22 September 1998.

5. King, M. D., "Earth Observing System: Science objectives and validation," at the School of Physics, University of New South Wales, Kensington, Australia, 24 September 1998.

6. King, M. D., "Clouds, radiation, and climate from the Earth Observing System," at the School of Physics, University of New South Wales, Kensington, Australia, 25 September 1998.

7. King, M. D., "Clouds, radiation, and climate from the Earth Observing System," at the Leeuwin Centre for Earth Sensing Technologies, Wembley, Australia, 2 October 1998.

III. Data/Analysis/Interpretation

a. FIRE ACE

MAS Data Processing

All eleven MODIS Airborne Simulator (MAS) Level-0 data for FIRE-ACE (flights #98-063 through #98-077) were completely processed to Level-1B HDF using a final calibration developed by NASA Ames. MAS Level-1B HDF archive tapes were created and then delivered to the Langley Distributed Active Archive Center (DAAC) for global distribution.

Web pages for each mission (flight) in the FIRE-ACE campaign are linked to the MAS web site. Updated configuration and spectral response files have been included. In addition, a web-based order form for all FIRE-ACE flights was created. A complete set of multi-band browse images for all flight tracks in the campaign is available, including several sample high-resolution 24-bit color images for selected flight tracks from each mission. The FIRE-ACE web pages are at http://ltpwww.gsfc.nasa.gov/MAS/fireacehome.html.

Tom Arnold implemented a process for merging selected data segments from several FRE-ACE ER-2 platform instruments into a single composite plot. Instruments used were the MAS (2 channels), MIR, AMPR and CLS. Data were obtained for each instrument and remapped (geometrically corrected) to the same resolution scale. Using this process data segments from 20 and 26 May 1998 (arctic stratus) were selected and composite plots produced for publication.

Figure 3 shows a composite of measurements obtained on 20 May just west of Barrow, where the flight crossed the Alaska coast line from snow-covered tundra to open water to fast ice. The MAS band at 0.66 µm is sensitive to reflected sunlight and is bright for clouds over snow-covered tundra and sea ice, but the stratus clouds were optically thin near the coast, allowing open water near the coast to be seen through the clouds. The 1.6µm band is sensitive to clouds, with open water and sea ice both being dark. As a consequence, the cloud is the most striking feature in this band. The AMPR sees through the cloud and shows strong contrast between open water (low emissivity at 37 GHz) and sea ice and snow-covered tundra, both of which have much larger brightness temperature. MIR is sensitive both to surface emission and atmospheric emission, and the

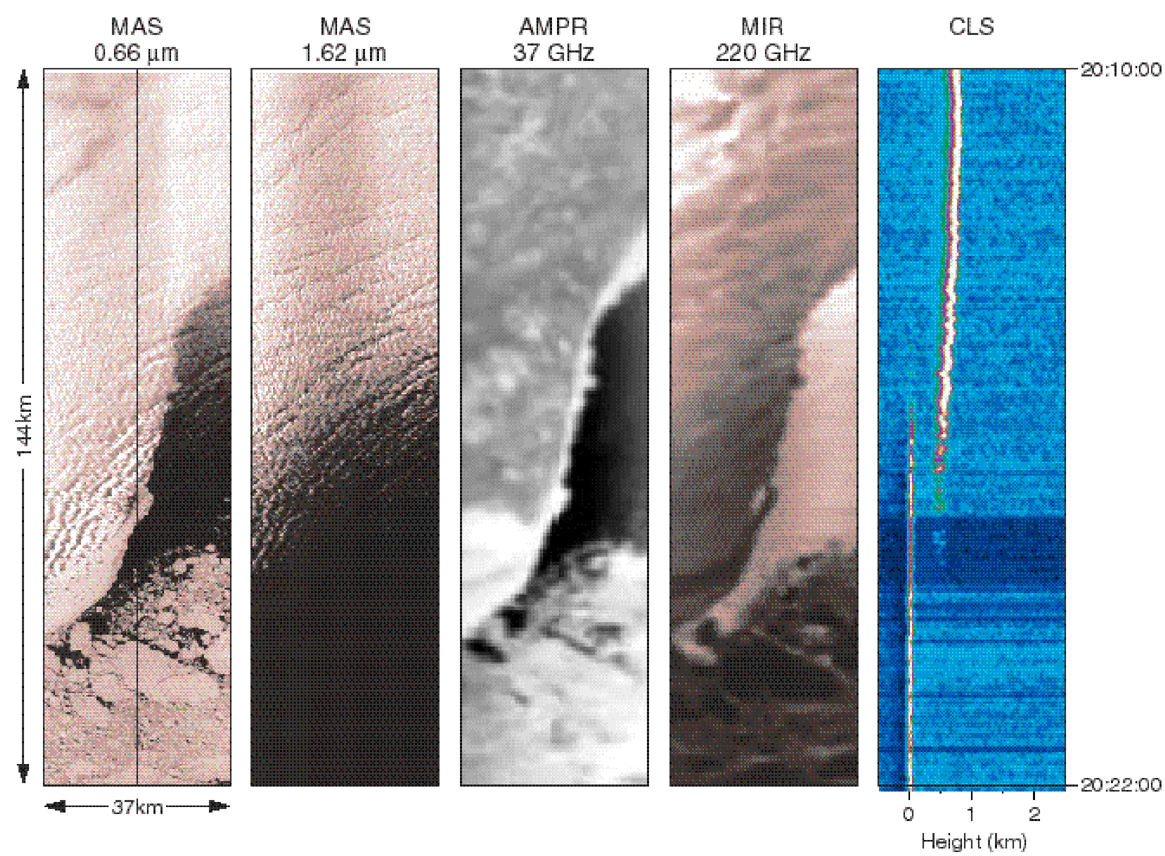

Figure 3. Composite images obtained for a 144 km flight line over the tundra, open water, and offshore fast ice on 20 May 1998. The ER-2 was flying down the image from top to bottom, encountering single layer Arctic stratus clouds with a cloud top altitude of around 600 m (CLS image on the right), followed by open water and fast ice. The MAS image at 0.66 µm showed semi-transparent clouds over open water, and the 1.62 µm image showed primarily high contrast between clouds and open water and sea ice, both of which have low reflectivity at that wavelength. Open water has low emissivity and hence low brightness temperature at the AMPR frequency of 37 GHz. The MIR saw higher atmospheric emission by water vapor over the open water than from the snow-covered tundra or sea ice.

open water has a higher brightness temperature due to emission by water vapor in the atmosphere. Finally, the CLS, which is a monostatic lidar that measures backscatter from the atmosphere along the nadir track of the aircraft (thin line in the first panel), shows that the Arctic stratus cloud is a single layer cloud perhaps 600 m above the surface, ending near the Alaska coast where the surface (open water and sea ice) are clearly seen.

Cloud Retrievals

Several MAS flights obtained during FIRE-ACE have been used for developing cloud retrieval algorithms over snow and ice surfaces. Retrieving cloud properties over highly reflecting surfaces is a difficult task, since multiple reflections between cloud and surface increase the overall reflectance at all non-absorbing channels. This in turn reduces the sensitivity on retrieving cloud properties or increases the possibility of getting multi-valued solutions. Cloud optical thickness and droplet size retrievals traditionally use a combination of spectral bands that are non-absorbing for water droplets (visible through 1.2 µm region) and longer wavelength absorbing bands (1.6, 2.1, and 3.7 µm), the former channels being the most sensitive to optical thickness and the latter channels having droplet size information. Snow/ice surfaces are both bright and variable at the shorter wavelengths, significantly increasing cloud optical thickness retrieval uncertainty. However, reflectances at the longer wavelengths absorbing bands are relatively small and may be comparable to that of dark open water. Steven Platnick has developed a modified retrieval algorithm using only the absorbing bands for which the snow/ice albedo is small.

Figure 4 shows a composite of a MAS visible image and retrievals using the new algorithm for an ER-2 flight over Barrow, AK on 6 June during FIRE-ACE. The optical thickness retrieval does not show the underlying discontinuities in the surface reflectance that are clearly seen through the cloud in the visible panel to

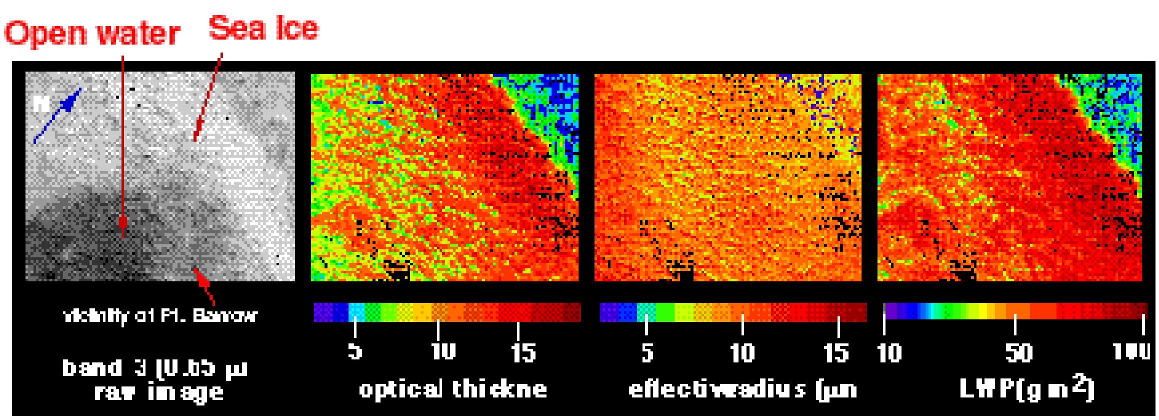

Figure 4. Cloud retrieval for a boundary layer stratus cloud overlying both bright sea ice surface and dark open water on 6 June 1998 just North of Barrow, AK during FIRE-ACE. The cloud deck was about 300 m thick with cloud tops at 900 m.

the left. Effective radius is uniform throughout the region. The cloud liquid water path (LWP) is shown in the right-most panel. Both retrievals are in good agreement with in situ instruments flown on the University of Washington CV-580. Comparisons are shown in Table 1. Other MAS scenes/days have analyze and will be subject of future work, including collaboration with other remote sensing instruments.

Table 1. Comparison of University of Washington CV-580 in situ data with the retrievals of Fig. 4 in the vicinity of the aircraft measurements.

Parameter	**MAS retrievals*** **(pixel average, standard deviation)**	**UW CV-580 (profile)**
τ	11.2	8.6 [1]
σ_τ	1.5	
r_e (μm)	9.4	9-10 [2]
σ_{re}	1.0	
LWP (g m^{-2})	70	60 [3]
σ_{LWP}	8	

**using 1.6 μm and 2.1 μm MAS bands*

1 g-meter probe, Gerber Scientific
2 FSSP, expected retrieval range with adiabatic vertical profile
3 PVM (using from H. Gerber)

Cloud BRDF Measurements

In support of cloud retrieval work, another goal of FIRE-ACE was the measurement of complete hemispheric cloud bidirectional reflectance distribution functions (BRDF) using the Cloud Absorption Radiometer (CAR) flown in the nose cone of the UW CV-580. The agreement between plane-parallel cloud models used in retrievals and real world clouds can be studied by comparing measured BRDFs with plane-parallel models based on in situ and/or MAS retrievals when coordination between the two aircraft was obtained. This work has been pursued by Steven Platnick and Jason Li.

Figure 5 shows a comparison between observation and plane-parallel theory for a midlevel stratus cloud from 3 June 1998 having cloud-top heights at about 3.5 km. In this instance, the cloud BRDF is clearly plane-parallel-like and retrievals would be expected to give uniform results regardless of view angle. Measurement of surface (snow/ice/tundra) BRDF were also made on that day, under both clear sky and diffuse sky (i.e., cloudy) conditions.

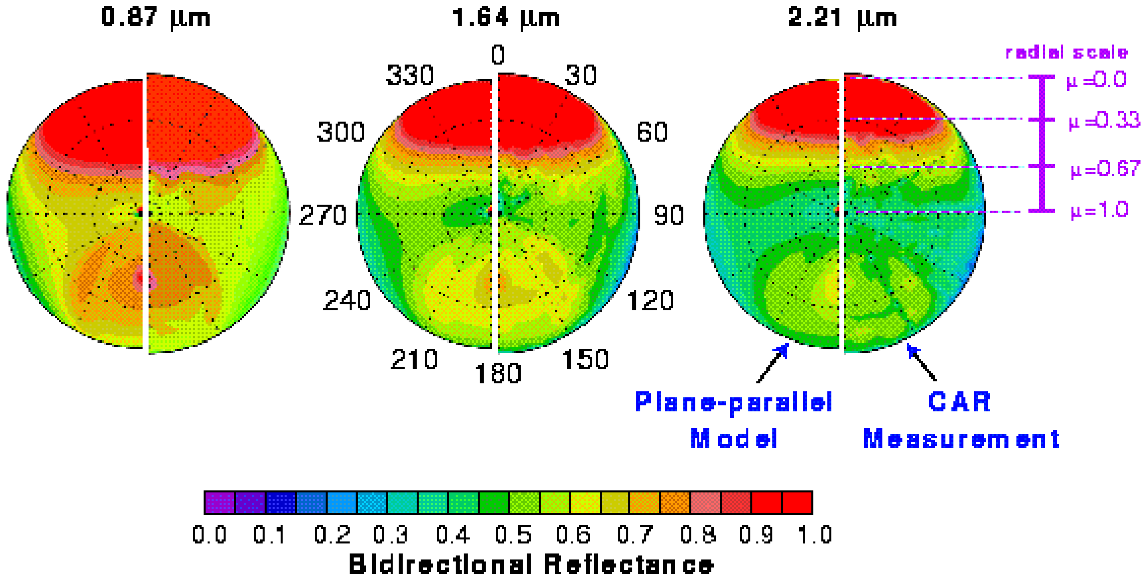

Figure 5. Comparison between the CAR-derived cloud BRDF and a plane-parallel model based on MAS retrievals for a midlevel stratus cloud on 3 June 1998 near the ice station SHEBA. The 0° relative azimuth in the polar contour plots corresponds to the solar azimuth, i.e., forward scattered photons are seen in the upper part of the plots (the solar zenith angle was 56.3°). The radial scale is the cosine of the nadir-viewing angle.

b. Ground-based Radiation Measurements

During the SCSMEX campaign IOP (1 May–30 June), Si-Chee Tsay successfully deployed a suite of surface remote sensing and radiation instruments at the Tungsha Island site in the South China Sea. The scientific objectives were two-fold: (1) to measure broadband shortwave and longwave irradiance at the surface, together with collocated satellite measurements, for studying the radiative energy budget at the IOP area, and (2) to acquire narrowband visible, near-infrared and microwave radiance measurements at the surface for retrieving atmospheric parameters (e.g., column water vapor amount, ozone abundance, aerosol loading and size distribution, etc.). It is expected that these data will be useful in support of cloud retrieval validation efforts. A brief summary of the instrumental specifications, data acquisition and processing status is given in Table 2.

The events of monsoon onset and passage through the Tungsha Island are clearly revealed from the measurements of downwelling longwave radiation. Figure 6 shows the diurnal variation of downwelling longwave radiation at the surface for three periods of pre-onset, onset, and break. During the monsoon onset period (red band), heavy cloud cover, acting as a warm blanket for the surface, largely suppressed the diurnal variation of downwelling longwave radiation. However, during the break period (blue band) the mostly clear-sky conditions cause a large diurnal difference in mean value but with small variations. These radiation data can currently be obtained from the PI (tsay@climate.gsfc.nasa.gov) and will eventually be distributed to the SCSMEX data center for distribution.

Table 2. Summary of surface remote sensing and radiation measurements.

Instrument	Specifications	Date Acquired	Processing Status
PSP Shortwave Radiometers	a. 0.3 - 2.8 µm b. 0.4 - 2.8 µm c. 0.7 - 2.8 µm	1-31 May, 1-9, 12-19, 24-30 June	Calibrated (final), off-set corrected
TSP Shortwave Radiometer	0.3 - 2.8 µm	Same as above	Temperature corrected (preliminary)
PIR Longwave Radiometer	4.0 - 50 µm	Same as above	Calibrated (preliminary)
MFR/7 Shad-owband Radi-ometer	416, 502, 616, 674, 869, and 938 nm	Same as above	Calibrated (preliminary)
Sunphotometer	340, 380, 440, 670, 870, 940, and 1020 nm	1-3, 6-17, 22-31 May, 7, 12-19, 21-30 June	Calibrated, without thin-cloud screen
Microwave Radiometers	a. 19 GHz b. 22 GHz	7 May to 7 July	Calibrated (preliminary)

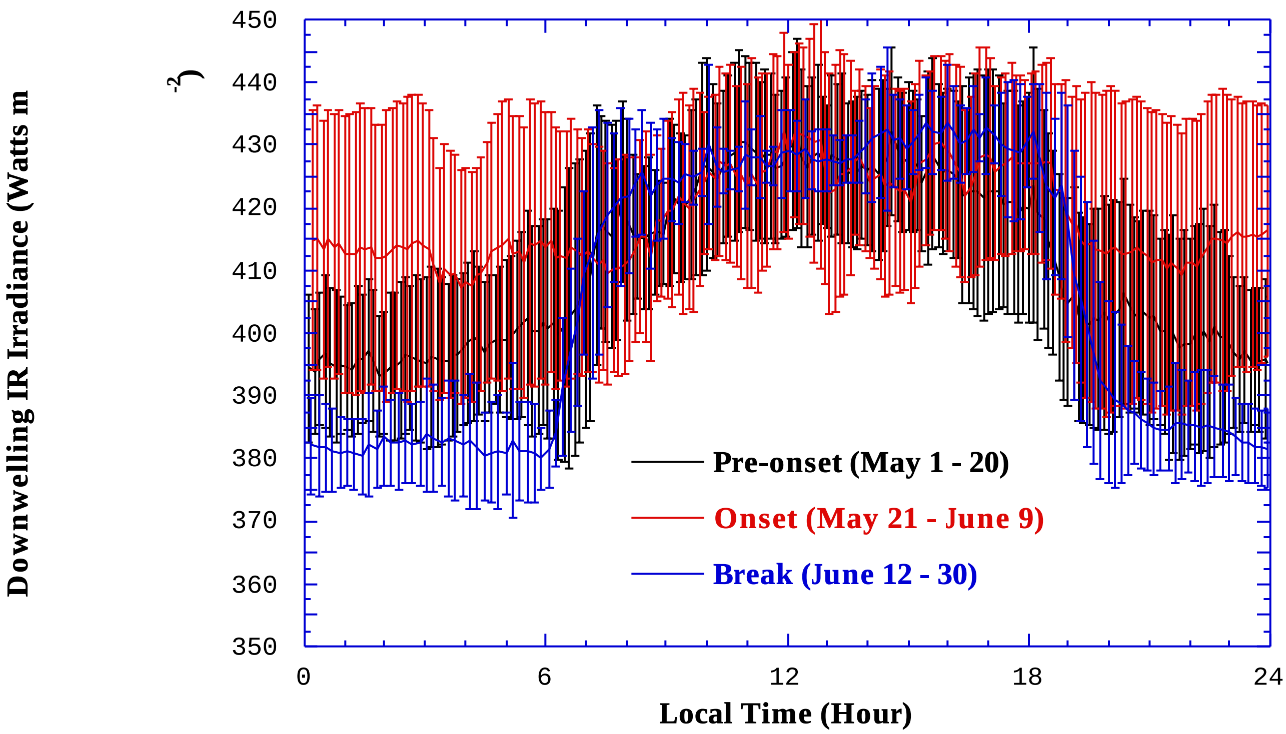

Figure 6. Measurements of downwelling longwave irradiance (4.0 - 50 µm) at the surface, data presented at 10-minute mean values and average (mean and standard deviation) for three observational periods.

In addition to these instruments, a new scanning microwave radiometer is under development and will be deployed in a pre-SAFARI campaign (August-September 1999). A new sun-photometer sensor head is also under development and will undergo engineering testing in the pre-SAFARI campaign.

IV. Anticipated Future Actions

a. Continue to test and refine our delivered MODIS *v2* cloud retrieval algorithm.

b. Complete the final library containing asymptotic theoretical parameters and functions for modeled ice clouds.

c. Continue to analyze surface bidirectional reflectance measurements obtained by the CAR during the Kuwait Oil Fire, LEADEX, ASTEX, SCAR-A ARMCAS, SCAR-B, TARFOX, and FIRE ACE experiments.

V. Problems/Corrective Actions

The main MODIS emphasis during the next reporting period is to improve the computational efficiency of the MOD06 cloud retrieval code to enable large scale processing of MODIS data in September.

VI. Publications

1. Ackerman, S. A., C. C. Moeller, K. I. Strabala, H. E. Gerber, L. E. Gumley, W. P. Menzel and S. C. Tsay, 1998: An infrared retrieval algorithm for determining the effective microphysical properties of clouds. *Geophys. Res. Lett.*, in press.

2. Gao, B. C., W. Han, S. C. Tsay and N. F. Larsen, 1997: Cloud detection over arctic region using airborne imaging spectrometer data. *J. Appl. Meteor.*, in press.

3. Kaufman, Y. J., P. V. Hobbs, V. W. J. H. Kirchhoff, P. Artaxo, L. A. Remer, B. N. Holben, M. D. King, S. C. Tsay, E. M. Prins, D. E. Ward, K. M. Longo, L. F. Mattos, C. A. Nobre, J. D. Spinhirne, A. M. Thompson, J. F. Gleason, and S. A. Christopher, 1998: The Smoke, Clouds and Radiation Experiment in Brazil (SCAR-B). *J. Geophys. Res.*, in press.

4. Kaufman, Y. J., R. Kleidman, M. D. King and D. E. Ward, 1998: SCAR-B fires in the tropics: Properties and their remote sensing from EOS-MODIS. *J. Geophys. Res.*, in press.

5. King, M. D., S. C. Tsay, S. A. Ackerman and N. F. Larsen, 1998: Discriminating heavy aerosol, clouds, and fires during SCAR-B: Application of airborne multispectral MAS Data. *J. Geophys. Res.*, in press.

6. Platnick, S., P. A. Durkee, K. Nielson, J. P. Taylor, S. C. Tsay, M. D. King,

R. J. Ferek, P. V. Hobbs and J. W. Rottman, 1998: The role of background cloud microphysics in the radiative formation of ship tracks. *J. Atmos. Sci.*, in press.

7. Rottman, J. W., S. Platnick, and M. D. King, 1998: Airborne observations of stratus clouds during the southerly surge event of 10-11 June 1994. Submitted to *Mon. Wea. Rev.*

8. Tsay, S. C., M. D. King, G. T. Arnold and J. Y. Li, 1998: Airborne spectral measurements of surface anisotropy during SCAR-B. *J. Geophys. Res.*, in press.

VII. References

Ackerman, S. A., K. I. Strabala, W. P. Menzel, R. A. Frey, C. C. Moeller, and L. E. Gumley, 1998: Discriminating clear-sky from clouds with MODIS. *J. Geophys. Res.*, in press.

Nakajima, T. and M. Tanaka, 1988: Algorithms for radiative intensity computations in moderately thick atmospheres using a truncation approximation. *J. Quant. Spectrosc. Radiat. Transfer,* **40**, 51-69.

Nakajima, T., and M. D. King, 1992: Asymptotic theory for optically thick layers: Application to the discrete ordinates method. *Appl. Opt.*, **31**, 7669-7683.

Stamnes, K., S.-C. Tsay, W. Wiscombe, and K. Jayaweera, 1988: Numerically stable algorithm for discrete ordinate and matrix operator method radiative transfer. *Appl. Opt.*, **27**, 2502-2509.